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STUDY ON MIX DESIGN & HARDENED PROPERTIES OF SELF-COMPACTING CONCRETE

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ABSTRACT

Self-compacting concrete represents one of the most significant advances in concrete technology for decades. The lack of skilled workers and need of good durability has led to its development but its growth throughout the world is somewhat hindered due to use of conventional filler materials like fly ash and silica fume, particularly at places where these are not available. The need of hour is the production of SCC at economical cost, so in this study work has been conducted for the production of SCC by the use of locally available aggregate and limestone as filler to take affordability in to account. The research work includes workability tests of SCC, their application in the development of mix design for SCC and finally exploring its hardened state properties. The various properties include compressive strength, split tensile strength, flexural strength, water absorption and finally tests like carbonation test and ultra sonic pulse velocity for durability study. The SCC showed better performance than conventional concrete and hence an economical high workability concrete can be produced without compromising on strength and durability properties.

KEYWORDS: SCC, Conventional Concrete, Workability, Super Plasticizer, VMA, Limestone

INTRODUCTION

In 1980's durability of concrete structures and lack of skilled labors become an important issue in Japan, an adequate compaction by skilled labors was required to obtain durable concrete structures. This requirement led to the development of self-compacting concrete. In 1986basic concept of SCC was given by Prof. Okamura of Tokyo University and its development was first reported in 1989. SCC is a high performance concrete which flows under its own weight without requiring vibrators to achieve consolidation by completely filling of formworks even when access is hindered by narrow gaps between reinforcing bars.

Although there is no established mix design procedure yet for SCC, Okamura and Ozawa have employed the following method to achieve self compatibility of SCC:

- Limited aggregate content (coarse aggregate 50% of concrete volume and sand 40% of mortar volume).
- Low water-powder ratio (determined by conducting number of trials).
- Use of higher dosage of super plasticizer

Since, self-compacting concrete is largely affected by the characteristics of materials and the mix proportions, it becomes necessary to evolve a procedure for mix design of SCC. Coarse aggregate and fine aggregate contents are fixed

and self compatibility is to be achieved by adjusting water/powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, fine aggregate is fixed at 40 percent of mortar volume and water/powder ratio depending on properties of powder and super plasticizer dosage. The required water powder ratio is determined by conducting number of trials. (Pratibha Aggarwal et.al). Saheed Adekunli et.al. concluded Utilizing natural pozzalana in conjunction with the other locally available waste materials(limestone powder, LSP, cement kiln dust and pulverized steel slag) as mineral fillers, it is possible to produce SCC mixtures with high strength 3, 7, 28 and90-day compressive strengths in the ranges of 36 to 49, 47 to 56, 65 to 68 and 70 to83 MPa, respectively. Al-Luhybi et al found that using LSP as replacement also led to economical advantages due to decrease in plasticizer content, with no noticeable differences in mechanical properties of SCC, but causing a fluidity increase of SCC when using LSP as an additive. Recent studies by M. Tennich et. al. showed the dosage of super plasticizer (SP) depends on the fineness of the aggregates. The more the fillers (limestone filler or wastes fillers from marbles and tiles factories) are fine, the more the dosage of SP decreases. Jinn Keun Kim conducted study on material properties of self-compacting concrete and concluded increase in rate of compressive strength of SCC is lower that of ordinary concrete at early ages but at late ages increasing rate of strength of SCC is higher than ordinary concrete. Also at the same compressive strength, splitting tensile strength of self flowing concrete is almost identical with the ordinary concrete. Rahul Dubey et.al. conducted a study on effect of super plasticizer dosages on compressive strength of self-compacting concrete and concluded with the addition of SP beyond 2% compressive strength decrease with the increase in dosage of SP. Laith A. Al Jaberi et. al. evaluated compressive strength of concrete by non destructive testing using using ultra sonic pulse velocity with maximum size of aggregate (10mm and 20mm). J. M Chi et. al. showed carbonation depth increase with increase in exposure time and higher Co_2 concentration results in higher carbonation depth for all mixtures.

TESTS FOR SCC

A concrete can be described SCC, if the requirements for all the properties filling ability, passing ability and segregation resistance are satisfied. No single test can give idea of all three workability properties, so many different methods have been developed to characterize the properties of SCC.

The Slump flow test measures the filling ability of SCC and gives some indication of resistance to segregation. The test method is based on conventional slump test. The diameter of concrete circle is a measure of filling ability of concrete. T_{50cm} test is a corollary slump flow test where T_{50cm} is the measure of time taken in seconds from the instant the slump cone is lifted to the instant when flow reaches a diameter of50cm.

The flow ability of SCC concrete can be tested by V-funnel test in which the funnel is filled with 12 liters of concrete. After 10 sec of filling, the trap door is opened to allow concrete to flow out under gravity. The stopwatch is started when the trap door is opened, and the time taken for complete discharge of concrete from funnel is recorded as 'flow time'. Shorter flow time indicate greater flow ability. T_{5min} is also measured with V-funnel which gives some idea for tendency to segregation. Here funnel is refilled with concrete and left as such for 5 minutes to settle before trap doors are opened. If concrete has tendency for segregation flow times will increase significantly.

The U-box test indicates the flow ability and passing ability of SCC. The two legs of U are separated by gate which has simulating reinforcing bars. The difference in height of concrete in two legs of U gives indication of passing ability of concrete.

The passing ability of SCC can also be measured with L-box test, where the vertical section of L box is filled with concrete and then the gate is lifted to allow the concrete to pass through the reinforcing bars in to the horizontal section of L box. When the flow has stopped, the ratio of height of concrete at end of horizontal section and to that remaining in vertical section (H_2/H_1) gives indication of passing ability of concrete.

Figure 1: Funnel Test Slump Flow Test

Figure 2: U-Box Test L- Box Test

MATERIALS USED

Cement: Portland cement of 43 grades conforming to IS: 8112-1949 specifications were used. Locally available cement with trade name JK cement was used.

Table 1: Properties of Cement

Physical Properties	Results Obtained
Fineness	8%
Normal consistency	29%
Vicats initial setting time(minutes)	72
Vicat final setting time(minutes)	220
Specific Gravity	
Compressive strength 3-day(Mpa)	22
Compressive strength 7-day(Mpa)	37
Compressive strength 28-day(Mpa)	45

Aggregate: The coarse aggregate used in this study were crushed stone. Both fine and coarse aggregate confirmed to IS: 383-1970.

Table 2: Properties of Aggregate

Characteristics	Coarse Aggregates	Fine Aggregate
Fineness modulus	6.55	2.67
Specific gravity	2.5	2.65
Water absorption (%)	0.85	1.2
Flakiness index (%)	11	_
Maximum size (mm)	20	_
Zone	-	II

Filler: Filler in this study is limestone.

Admixture: Sulphonated naphthalene formaldehydewas used as super plasticizer. A high performance cohesion agent named “Sika stabilizer 229” specially designed to ensure good consistency and stability in concrete was used as stabilizer.

Table 3: Admixture Properties

Admixture	Super Plasticizer	Viscosity Modifying Agent
Brand name	Structure 220	Sika stabilizer 229
Specific gravity	1.08	1.02
pH	6.5	-

EXPERIMENTAL PROCEDURE

- Eight trial mixes were prepared by varying the limestone powder content, fine to coarse aggregate ratio and super plasticizer content
- Two levels of limestone powder 100kg/m3 and 125kg/m3, two levels of fine to coarse aggregate ratio: 1 and 1.1 (by mass) and two levels of super plasticizer (Sulphonated naphthalene formaldehyde):0.8% and 1% by mass of powder were used for preparing and testing eight trial mixes.
- For each trial mix constant cement content (350kg/m^3) and constant amount of stabilizer (3kg/cum) were taken.
- Tests such as Slump flow, V funnel and U box were carried out for each trial mix followed by compressive strength tests and trial mix which showed best in strength and workability properties was selected for further tests in hardened state.
- Selected SCC mix was checked for hardened state properties like flexural strength, split tensile strength, compressive strength and water absorption.
- Finally, casting results were compared with the test results obtained from conventional concrete with same cement content i.e., 350 kg/cum of concrete and w/c ratio of 0.55.

Table 4: Weight of Constituents in Trial Mixes

Trial mix	Mix Variables			Quantities of Ingredients (kg/cum)					
	FA/CA ratio	Filler content kg/m3	SP %	Water kg/m3	Cement kg/m3	FA kg/m3	CA kg/m3	SP kg/m3	Stabilizer kg/m3
A	1	100	0.8	190	350	845	845	3.6	3.00
B	1	100	1.0	190	350	845	845	4.5	3.00
C	1	125	0.8	199	350	820	820	3.8	3.00
D	1	125	1.0	198	350	820	820	4.7	3.00
E	1.1	100	0.8	190	350	890	808	3.5	3.00
F	**1.1**	**100**	**1.0**	**189**	**350**	**890**	**808**	**4.5**	**3.00**
G	1.1	125	0.8	198	350	860	780	3.8	3.00
H	1.1	125	1.0	197	350	860	780	4.7	3.00

Table 5: Self Compatibility and Average Compressive Strength of Trial Mixes

Trial mix		Workability Properties						Compressive Strength	
	Slump flow (mm)	T_{50cm} slump flow (sec.)	V-funnel (sec)	V-funnel at T_{5min} (sec.)	U-box (mm)	L-box	VSI	7 day (Mpa)	28 day (Mpa)
A	650	4.5	10	13	19	0.75	1	16.58	23.88
B	690	3	6	8	25	0.83	1	17.79	27.79
C	720	2	8	10	29	0.86	1	16.95	22.36
D	710	2	8	9	28	0.82	0	17.91	27.41
E	680	3.5	8	10	36	0.67	1	16.20	22.86
F	**750**	**3**	**7**	**9**	**15**	**0.96**	**0**	**18.34**	**29.09**
G	730	3	7	11	26	0.81	0	17.60	27.33
H	730	3	7	10	6	0.88	0	17.94	27.50

Trial mix F was selected for further research on the basis of its high workability and compressive strength compared to other mixes. Further tests were conducted to evaluate compressive strength, split tensile strength, and water absorption and durability properties of self compacting concrete.

TEST RESULTS FOR TRIAL MIX F

Compressive Strength Test

Compression strength testing machine is used to determine the compressive strength of a test specimen. The size of cube specimen used to perform test is 150mm × 150mm × 150mm (IS: 516 – 1959). A test result is the average of at least three standard cured specimens made from the same concrete sample and tested at the same age. Test should be performed for at least 3 cubes and average value at curing period of 7 day, 14 day and 28 day is taken.

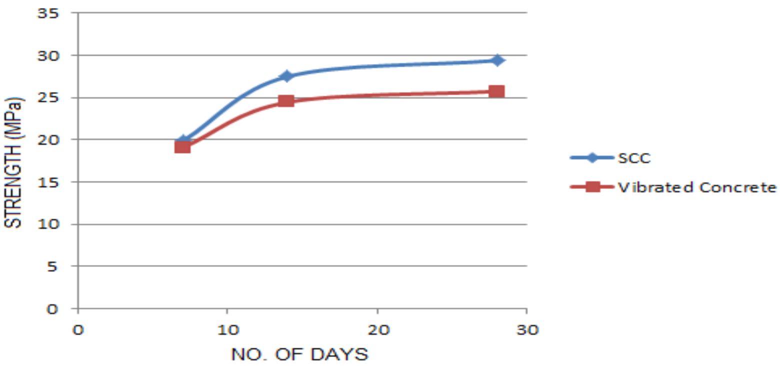

Figure 3: Compressive Strength

Split Tensile Test

Split tensile strength test consists of applying diametric compressive force along the length of a cylindrical specimen. The size of the specimen is 150mmØ × 300mmL (IS: 516 – 1959). The loading induces tensile stresses on the plane containing the applying load and tensile failure occurs rather than compressive failure. At least three specimens shall be tested for each age of tests (IS: 5816- 1999) and average value at curing period of 7 day, 14 day and 28 day is taken.

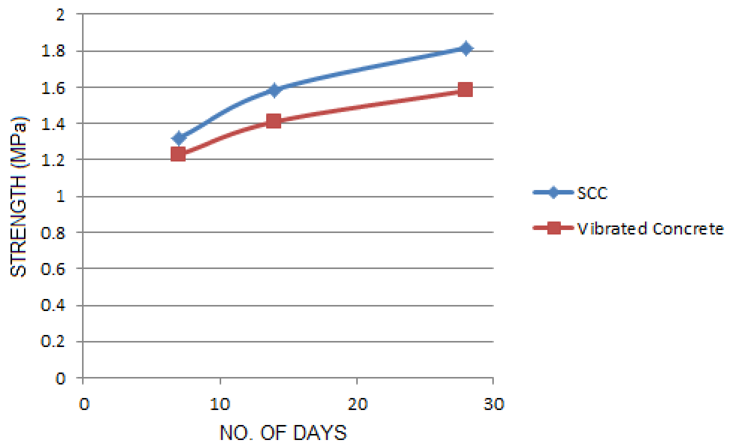

Figure 4: Split Tensile Strength

Flexural Strength Test

A beam test is found dependable to measure flexural strength properties of concrete and same is applied for SCC. Standard beam test or modulus of rupture test carried out on the beams of size 100mm×100mm×500mm (IS: 516 - 1959), by considering the material to be homogeneous. The beams should be tested on a span of 400 mm for 100 mms specimen by applying two equal loads placed at third points.

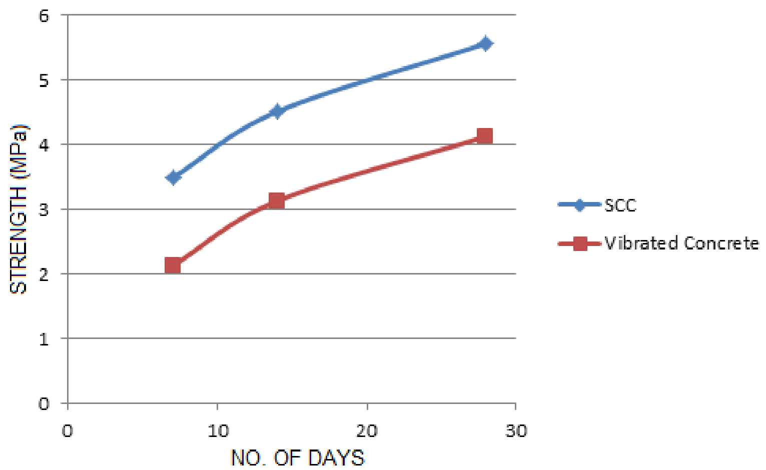

Figure 5: Flexural Strength

Water Absorption of SCC Specimen

The water absorption of the concrete cylindrical specimens was determined according to conventional method. Water absorption tests were taken up after 28 days of curing. As per previous data available, the water absorption of conventional concrete is about 5%, (research project report, 2000). The 300 x 150 mm cylindrical concrete specimens were

dried in an oven at a temperature of 100 to 110 C for not less than 24 hours. They were allowed to cool to room temperature and weighed (W1). Then they were immersed in a water bath at approximately 25 C for not less than 24 hours. After removing from the water bath, the cylinders were surface-dried and weighed (W2). Water absorption for SCC was determined using the following relationship:

Absorption % = (W2-W1) / W1 x 100.

Table 6: Water Absorption of SCC Specimens

Sample	Actual Weight (g)	(W_1 g) Weight after Drying	(W_2 g) Weight after 24 hrs of Soaking	Absorption (%) =[W2-W1] x100 / W1
1	12437.00	12405.00	12739.00	3.34
2	12553.00	12521.00	12892.00	3.71
3	12499.00	12468.00	12800.00	3.32
AVERAGE				3.456

Carbonation Test

Carbon dioxide can penetrate through concrete surface and react with alkaline components in cement of concrete which results in reduction of pH value to a value less than nine. The depth of carbonated layer is called depth of carbonation. The cross section of concrete specimens taken was 100mm × 100mm and was split in to lengths of 50mm for testing. The sample was placed in carbonation chamber and was taken out at regular intervals to measure the depth of carbonation. The depth of carbonation was measured by splitting the sample and spraying with phenolphthalein solution (1% phenolphthalein in 70% ethyl alcohol) as indicator, which turns non carbonated concrete red and shows no color change on carbonated concrete because phenolphthalein is a colorless indicator which turns red when pH is above 9.5. At each age of carbonation (3, 7, 28 and 56 days) at least depth was measured to a nearest mm at four places and average was taken as carbonation depth at that age of concrete. The results of carbonation test are tabulated below.

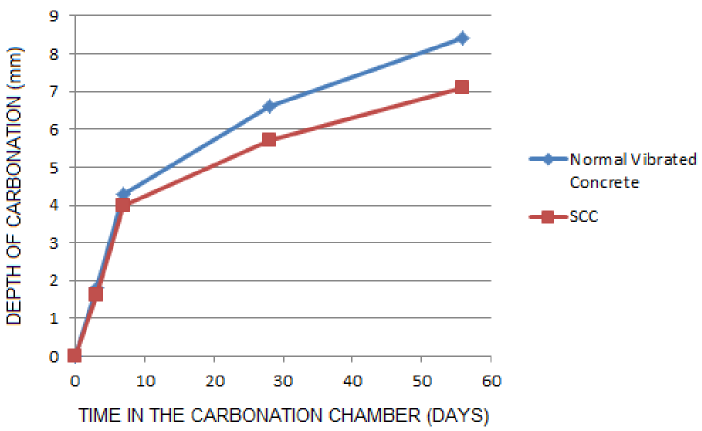

Figure 6: Carbonation Test

Ultra Sonic Pulse Velocity

It is a non destructive testing method which determines the velocity of ultra sonic wave passing through the concrete (IS 1311-1:1992). This method helps to predict relative quality of concrete, to indicate the presence of voids and cracks, assess deterioration and changes in properties of concrete. In this method, pulse of longitudinal vibration is

produced by electro-acoustical transducer which is held with one surface of concrete and the first wave which reaches the receiving transducer is longitudinal wave. There must be a smooth contact with the surface under test and therefore a coupling medium such as thin film of oil should be used. Electronic circuits help to measure to measure transit time over the path lengths ranging from 100mm to maximum thickness of specimen. Generally frequency of transducers used is in the range 20 to 150 kHz. Cube specimens of size 150mm × 150mm × 150mm were used in the test and results are tabulated below:

Table 7: Concrete Quality Grading from Velocity Grading

Sample	Ultra Sonic Pulse Velocity km/s	Concrete Quality Grading
Normal vibrated concrete	4.48	Good
SCC	4.63	Excellent

CONCLUSIONS

- From eight trial mixes, a mix with FA/CA ratio of 1.1, filler content of 100 kg/m3 and 1.00% super plasticizer was found to meet the compactibility criteria and possessed maximum compressive strength.
- The strength of SCC specimens increased with the time of curing.
- The SCC specimens displayed better performances with regard to water absorption. The water absorption of specimens exposed to normal laboratory conditions was 3.51% against 5% of conventional concrete.
- Effect of different super plasticizer on strength is small and is of the order of 2-3 N/mm^2.
- The selected SCC mix showed better strength and durability properties than corresponding conventional concrete.
- SCC mix showed better resistance to similar carbonation test environment than conventional concrete.
- The pulse velocity criteria suggested concrete quality of selected mix of SCC is better than normal conventional concrete.

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